HDL-TM-83-6

June 1983

Physical and Computer Modeling of Military Earth Grounding Practices in a HEMP Environment

by Andrew A. Cuneo, Jr.
James J. Loftus
Rodney A. Perala

U.S. Army Electronics Research and Development Command
Harry Diamond Laboratories
Adelphi, MD 20783

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: HDL-TM-83-6
2. GOVT ACCESSION NO.: AD-A130141
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): Physical and Computer Modeling of Military Earth Grounding Practices in a HEMP Environment
5. TYPE OF REPORT & PERIOD COVERED: Technical Memorandum
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s): Andrew A. Cuneo, Jr., James J. Loftus, Rodney A. Perala, Electro Magnetic Applications, Inc., Denver, Co
8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Harry Diamond Laboratories, 2800 Powder Mill Road, Adelphi, Maryland 20783
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: Program Ele: 33126K
11. CONTROLLING OFFICE NAME AND ADDRESS: Defense Communications Engineering Center, 1860 Wiehle Avenue, Reston, VA 22090
12. REPORT DATE: June 1983
13. NUMBER OF PAGES:
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): UNCLASSIFIED
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Approved for public release; distribution unlimited.
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report):
18. SUPPLEMENTARY NOTES: PRON: WSO-4001WSA9; MIPR: HC1001-9-400
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
HEMP
Grounding
Electronic systems
Hardening
Scale modeling
Finite-difference transmission-line technique

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Military grounding practices compatible with hardening electronic systems to high-altitude electromagnetic pulse (HEMP) illumination are considered. This study concerns the grounding practices outlined in MIL-STD-188-124, Common Long-Haul/Tactical Communications Systems. Three standard grounding schemes and one new scheme were chosen for study at a 10:1 scale, illuminated by a 59-V/m peak simulated HEMP. There were several significant results:

(a) The theoretical technique in general agrees to within a factor of three with the experimental results.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Cont'd)

(b) The type of earth ground system does not appear to be important,

(c) Intrasite transients tend to be dominated by electromagnetic coupling to completed conductive loops. When the loop is broken, the transient is characterized by the half-wavelength resonance of the conductor. Grounding paths which do not form part of the loop do not contribute significantly to the transient in the loop.

CONTENTS

FIGURES

TABLES

1. INTRODUCTION

1.1 Background

In recent years, there has been a resurgence of interest in military grounding practices which are compatible with hardening electronic systems to high-altitude electromagnetic pulse (HEMP) illumination. This study concerns the grounding practices outlined in MIL-STD-188-124, Common Long-Haul/Tactical Communications Systems. Considerable controversy surrounds the topic of grounding practices. None of these practices have been subjected to rigorous HEMP analysis and testing to determine the most effective configuration. To accomplish this goal, 10:1 scale models of three standard grounding schemes and one new scheme (fig. 1 to 4), illuminated by simulated HEMP, were mathematically modeled and tested. The theoretical study used finite-difference transmission-line techniques for scale models of buried and surface conductor configurations. The simulated HEMP tests were performed at the Harry Diamond Laboratories (HDL) Scale-Modeling Facility in the Facility for Research in Electromagnetic Effects (FREME).

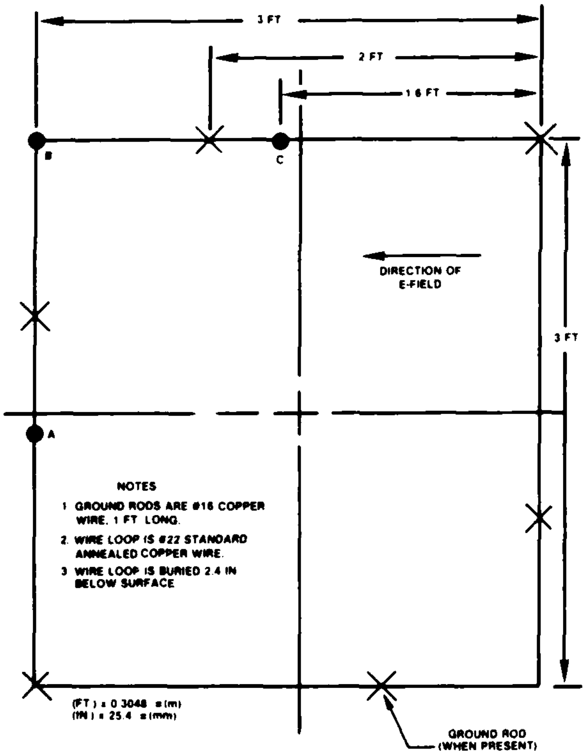

Figure 1. Ground loop model. Positive wire current is counterclockwise.

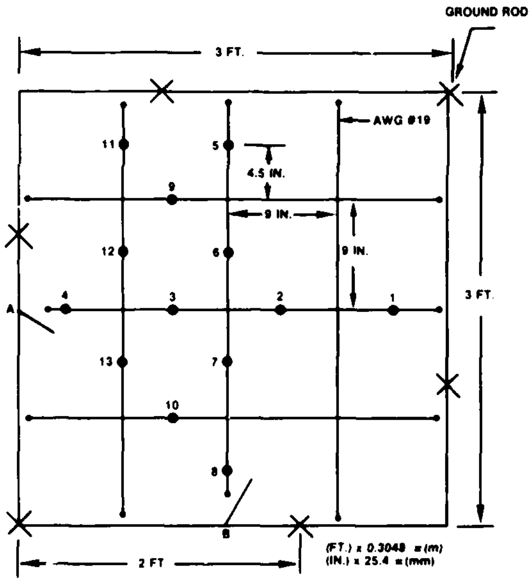

Figure 2. Rebar model, occasionally connected to counterpoise (ground loop) at A or B. Direction of E-field as in figure 1.

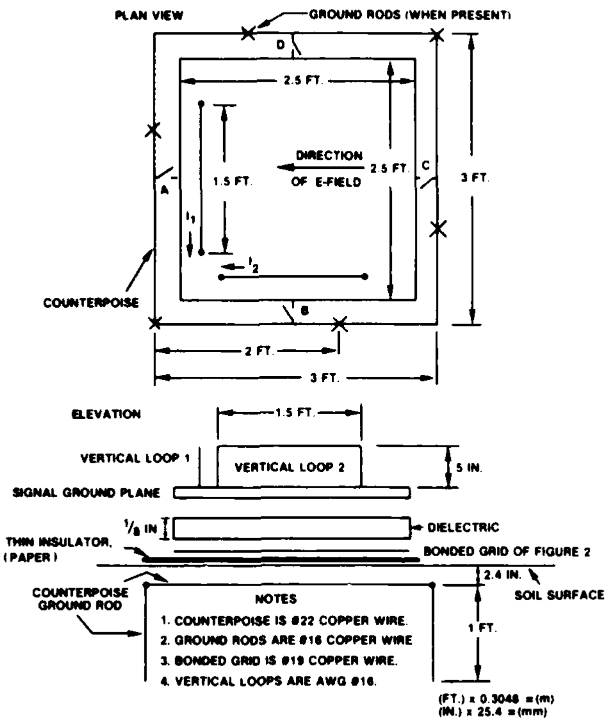

Figure 3. Signal ground plane with earth counterpoise system.

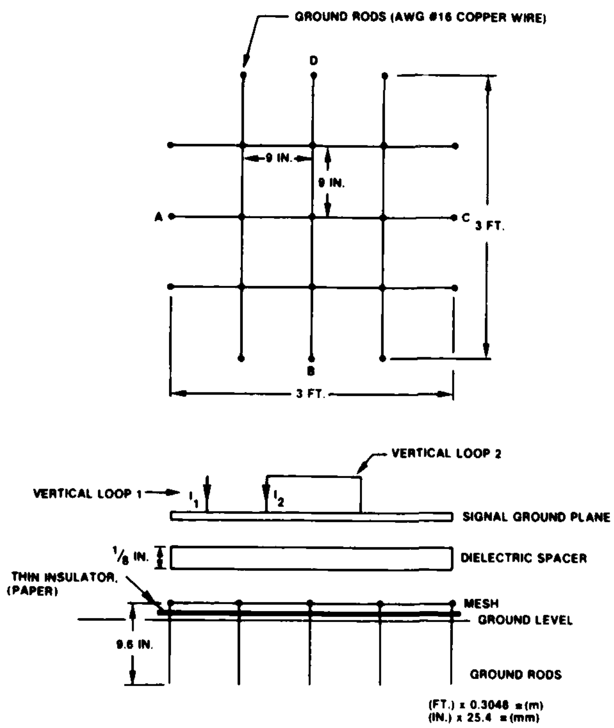

Figure 4. Model for new earth ground system.

1.2 Objectives

The objectives of the study of grounding practices are to determine the

(a) EMP response of an earth ground system,
(b) effectiveness of ground rods,
(c) effects of an earth ground system on coupling to facility equipment, and
(d) effectiveness of a signal ground plane.

Three of the most commonly used grounding systems and one new type have been selected for study. They possess one or more characteristics of all systems. It is desirable to ascertain the relative merits of grounding schemes of varying levels of sophistication. A longer term goal is to develop and test theoretical modeling techniques for grounding practices. A successful theory provides an alternative to extensive testing to empirically determine EMP hardening practices.

2. ANALYTICAL AND EXPERIMENTAL APPROACH

2.1 Experiments

The coupling source is a plane wave 50-kV/m double exponential HEMP threat scaled to 59 V/m in the tests and the model. The physical scale is approximately 10:1. The resulting current is measured at each of the test points. The four experiments are summarized in the following paragraphs.

Experiment 1: ground loop only.--In the first experiment, the test object is a simple square loop, as shown in figure 1. Current on the loop at points A, B, and C is measured with and without the ground stakes. The objective here is to investigate the effects of ground rods and provide a basis of theoretical and experimental comparisons for the simplest geometry.

Experiment 2: ground loop plus coarse rebar structure.--The second experimental configuration is shown in figure 2. This configuration is the same as in experiment 1, except that a bonded grid mesh is within the loop as shown. This grid lies on the soil surface. The grid may or may not be connected to the ground ring at points A and/or B. In this experiment, the ground rods are always connected and in place. The measured currents consist of wire currents at test points 1 through 12. In this experiment, the wire mesh represents a facility ground mesh, and the intent is to determine how connection to the earth ground system affects the current distribution on the mesh.

Experiment 3: response of signal ground plane with counterpoise earth ground system.--The configuration for this experiment is given in figure 3. This has the same earth ground configuration as figure 2. In the present case, the facility and signal ground systems consist of the bonded grid (fig. 2), which lies on top of the soil, the 1/8-in.-thick dielectric spacer, and then the metal ground plane on top. The metal plane has two loops on it, as

shown. Currents I_1 and I_2 are measured in this experiment. The signal ground plane is connected to the bonded grid (the facility ground) at only one place at a time, either A or B. For each of these cases, the current is measured for the bonded grid connected to the earth ground subsystem at points A only; B only; A and B; A, B, and C; and A, B, C, and D. The objective is to determine how the connection of the facility and signal ground planes affects coupling to facility equipment.

Experiment 4: response of signal ground plane with new earth ground system.--The configuration for this experiment is shown in figure 4. This configuration is the same as that of figure 3, except that the facility earth electrode system is different. The signal ground plane with the two loops is the same in both figures.

In the present case, instead of using a counterpoise, the earth electrode subsystem used numerous ground rods attached to a mesh identical to the one in figure 2. This facility ground may be connected to the signal ground points A, B, C, or D. Currents I_1 and I_2 are measured for connections made at A; B; A and B; A, B, and C; and A, B, C, and D. The objective here is the same as that of experiment 3, except with a different earth ground system.

2.2 Analytical Technique

Electro Magnetic Applications, Inc., of Denver, CO, was contracted to perform the calculations. The goal is to model the time-domain current in a grounding system which results from illumination by a HEMP. This first requires modeling a generalized EMP in free space striking a plane interface with a medium of frequency dependent σ, ϵ, and μ. Two computer codes, 1TOP and 1DEEP, were developed for the surface reflection and refraction, respectively. Both codes require a Fourier transform capability and must be able to solve the standard plane wave Fresnel equations. With an input of the original wave, $\sigma(\omega)$, $\epsilon(\omega)$, and $\mu(\omega)$--the pulse shapes at the burial depth and on the surface--are obtained.

In the second part of the analysis, the loop and rebar structures were modeled by use of a time-domain buried cable code, NEDBC. This code was modified for a ground loop by setting the potentials of the end-points equal. Nonlinearities were neglected. Furthermore, the rebar intersections are treated using Kirchoff's laws, otherwise neglecting the mutual interactions of wires.

The methods for calculating wire resistances (R) per unit length, capacitances (C) per unit length, inductances (L) per unit length, conductances (G) per unit length, currents (I), and voltages (V) are discussed in the following paragraphs.

The methods involve the solution of the transverse electromagnetic (TEM) transmission-line equations

$$\frac{\partial I}{\partial X} = -\frac{\partial(CV)}{\partial t} - GV \quad , \tag{1}$$

$$\frac{\partial V}{\partial X} = V_s - \frac{\partial(LI)}{\partial t} - IR \quad , \tag{2}$$

where V_s is the voltage source which arises from the tangential incident electric field. The transmission-line parameters are defined as follows:

$$C = \frac{2\pi\varepsilon}{\ln\left(\frac{r_w + \delta}{r_w}\right)} \quad , \tag{3}$$

where

$$r_w = \text{radius of wire and}$$

$$\delta = \text{skin depth in earth} = 0.794\left(\frac{2t}{\mu\sigma}\right)^{1/2} \quad , \tag{4}$$

with the assumption

$$\frac{\pi}{2} = \omega t \quad .$$

Also,

$$L = \frac{\mu}{2\pi} \ln\left(\frac{r_w + \delta}{r_w}\right) = \frac{\mu\varepsilon}{C} = \frac{1}{v_p^2 C} \tag{5}$$

(coaxial inductance), where v_p is the propagation velocity of the medium and

$$G = \frac{\sigma}{\varepsilon} C \quad . \tag{6}$$

Ground rods are included as a perturbation to G at the appropriate spatial location. Resistances were obtained from standard formulas,[1] with the result that for a 1-ft ground rod the resistance is 70 Ω for a soil conductivity of 0.05 mho/m. The relative dielectric constant used in the calculation was 3.5, although the dielectric constant does not significantly affect the results.

---

[1] *E. D. Sunde, Earth Conduction Effects in Transmission Systems, Dover Publications, Inc., New York (1968).*

For the mesh above the earth, surface cable code techniques were used. The parameters are the same as those used for the buried cable analysis, except that the capacitance is halved and the inductance is doubled.[2]

2.3 Excitation Used and Relationship to HEMP Threat

Electromagnetic scale modeling[3] of grounding systems for experimentally determining external coupling features requires the generation and measurement of radiated pulses closely resembling the critical characteristics of a HEMP. For the scale-modeling facility, HDL has developed a simulator consisting of a resistively tapered dipole antenna driven by a nanosecond pulser. This results in a simulated HEMP, shown in figure 5, with a 59-V/m peak and a 0.78-ns rise time at the test object location. The distortion region between 47 and 100 ns is due to late time behavior of the antenna and error introduced due to the integration of the measured signal (using a B sensor) buried in the noise. To compare the model values to the full-scale HEMP threat values, the following formula is used:

$$I = \left(\frac{50\ \text{kV/m}}{59\ \text{V/m}}\right)(10)(I') \quad ,$$

where

I' = "1/10 model" current

and

I = full-scale HEMP data.

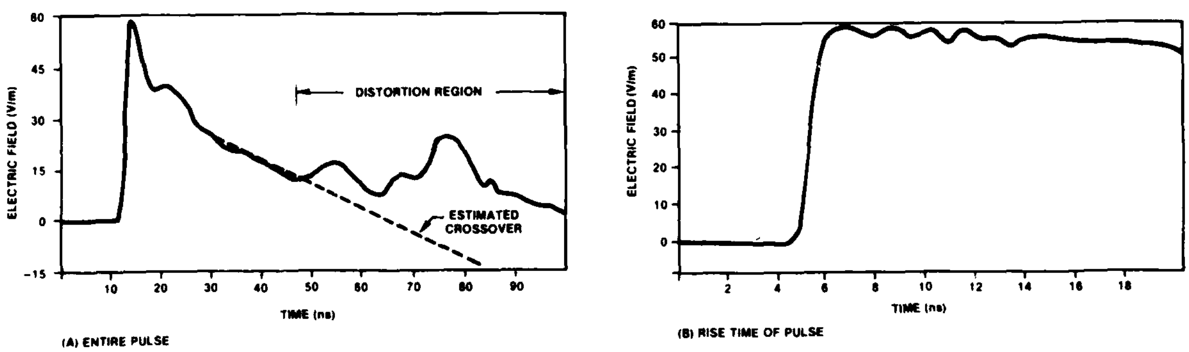

Figure 5. Incident simulated HEMP electric field.

---

[2] *R. A. Perala and R. B. Cook, The Effects of Dielectric and Soil Nonlinearities on the EMP Response of Cables Lying on the Surface of the Earth, Electromagnetic Applications, Inc., Denver, CO, EMA-79-P-3 (January 1979).*

[3] *G. Sinclair, Theory of Models of Electromagnetic Systems, Proceedings of IRE (November 1948), 1364-1370.*

Techniques for measuring the amplitude of the scaled-down HEMP waveforms have been developed by HDL at the Scale-Modeling Facility.[4]

2.4 Test Setup

The HDL Scale-Modeling Facility occupies a large structure at the North Annex of Fort Belvoir, VA. The structure, which is known as the FREME, is approximately 46 × 30 m, with the highest point of the roof 15 m above the floor. The modeling is carried out in an 18- × 24-m* box containing chemically treated sand.[5] For this effort, the depth of the sand was built up to accommodate the ground rods.

The scaled-down grounding systems, shown in figures 1 to 4, are embedded in or placed on the chemically treated sand. A 40-ft† long resistively tapered dipole antenna is suspended 2.5 m above the sand over the model. This antenna is driven by the nanosecond pulser. Time-domain sampling techniques are used to observe the response of the scaled-down ground systems to the scaled-down HEMP. Tektronix CT-1 current probes are attached to particular test points for each test. The recording instrumentation consists of a digital processing oscilloscope controlled by a Tektronix WP1221 Signal Processing System. The measurement points are identified in figures 1 through 4.

3. RESULTS OF EXPERIMENTS

3.1 Results of Experiment 1

Typical predicted and measured waveforms for experiment 1 are compared in figure 6. Table 1 summarizes a comparison of peak values.

It is noted that peak values are predicted within a factor of 2 to 3. The pulse shapes agree quite well, although the predicted pulses are much wider than those measured.

The data support the following conclusions:

(a) The mathematical model predicts peak values within a factor of 3.

---

[4] *Andrew A. Cuneo, Jr., and James J. Loftus, Measurement of Scaled-Down High Altitude Electromagnetic Pulse (HEMP) Waveforms, Harry Diamond Laboratories, HDL-TM-81-6 (March 1981).*

[5] *Andrew A. Cuneo, Jr., and James J. Loftus, Scale Modeling for the Patriot Electromagnetic Pulse Test, Harry Diamond Laboratories, HDL-TM-81-16 (May 1981).*

(in.) × 25.4 = (mm).

†*(ft) × 0.3048 = (m).*

(b) The mathematical model predicts at least as large or larger effects of the ground rods as was measured, but in all areas the effects of the ground rods appear to be practically insignificant.

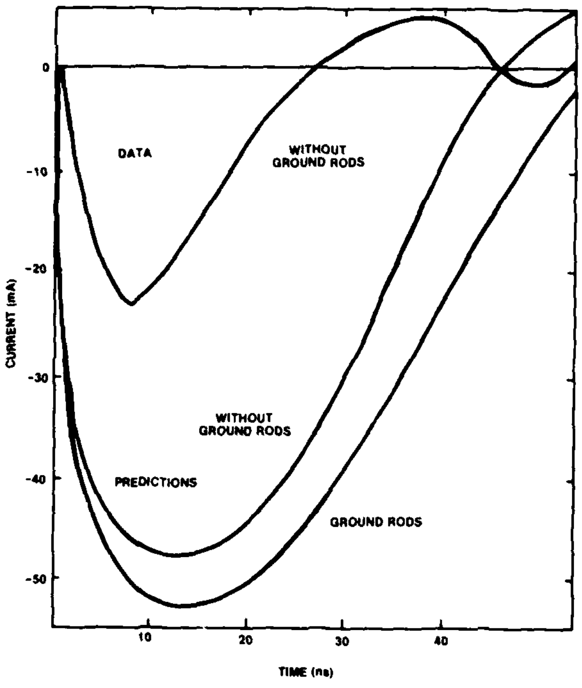

Figure 6. Experiment 1: predictions and data at point B.

TABLE 1. SUMMARY OF COMPARISON OF PREDICTED AND MEASURED PEAK VALUES FOR EXPERIMENT 1

Test point	Peak amplitude (mA)			
	With ground rods		Without ground rods	
	Predicted	Test	Predicted	Test
A	5	8	3	9
B	53	24	48	22
C	84	41	72	38

3.2 Results of Experiment 2

Overlays of typical measured and predicted responses for experiment 2 are shown in figure 7. Table 2 summarizes a comparison of peak values. The predictions of principal responses agree quite well with measurements in peak amplitude, but again the predicted waveshapes are broader than those measured. The model predicts nonprincipal responses to be zero by symmetry. The measured values then indicate how well the experiment is laid out. This appears to have been well done, because of the small values indicated. The data support the following conclusions:

(a) Principal predictions in general agree with measurements to within 33 percent.

(b) For the principal responses, in general, only an insignificant effect caused by the different connections is noted. It therefore does not seem to make a great deal of difference where, if, or how many times the ground systems are connected together.

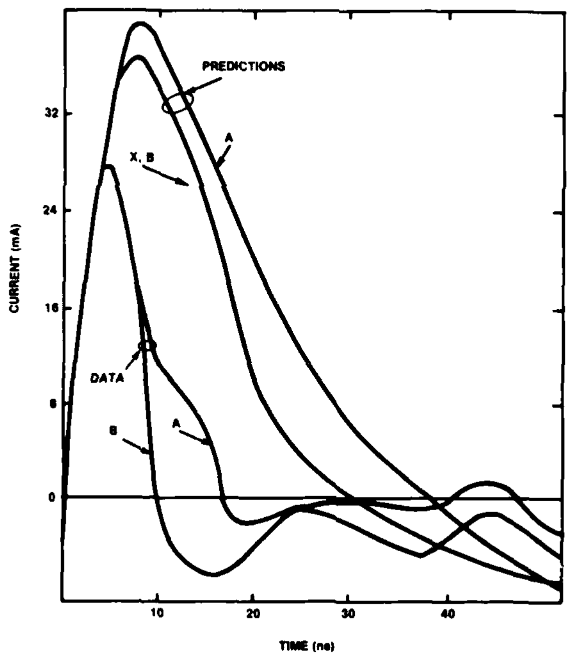

Figure 7. Experiment 2: predictions and data for wire current at point 2 (A--connected to counterpoise at A, B--connected at B, X--not connected to counterpoise).

TABLE 2. PEAK VALUE OF MEASURED AND PREDICTED CURRENT (mA) RESPONSES FOR EXPERIMENT 2

Test point	A open, B open		A closed, B open		A open, B closed		A closed, B closed	
	Experiment	Model	Experiment	Model	Experiment	Model	Experiment	Model
1	15	18	15	18	15	18	15	-
2	28	37	28	39	28	37	28	-
3	27	35	29	45	27	35	29	-
4	14	14	35	51	14	14	36	-
5	1	0	2	2	1	0	2	-
6	2	0	2	11	1	1	2	-
7	1	0	3	10	2	1	7	-
8	1	0	2	1	5	6	19	-
9	29	36	29	37	29	36	29	-
10	30	36	30	37	30	36	30	-
11	13	10	11	9	13	10	11	-
12	3	-	12	-	2	-	12	-
13	7	1	12	24	7	1	12	-

3.3 Results of Experiments 3 and 4

Comparisons of predicted and measured results are shown in figures 8 through 10. Figures 8 and 9 show overlays of I_2. The peak values agree within a factor of two, and the general waveforms are of similar shape. The principal difference is that the predictions (which were obtained by simply allowing the current to be the ratio of the magnetic flux to the loop inductance), did not include the resonances which do appear in the data. Figure 10 shows the response I_2 without a metal ground plane;* that is, the ends of the wires are simply inserted into the sand. It is noted that the peak response is about the same, but the shape of the waveform is changed by the soil (see app A). The responses of I_1 are predicted to be zero by symmetry.

The data support several conclusions:

(a) Results from experiments 3 and 4 agree within experimental error; hence, there appears to be no significant difference caused by the type of earth ground system used.

(b) Whether or not, how often, or where the signal ground plane is connected to the earth ground system does not appear to make any significant difference in the response of overhead cables in a facility. The cable response appears to be independent of the ground connections, as long as there is a signal ground plane present to complete the loop.

---

*I_2 *is measured at the wire/sand interface.*

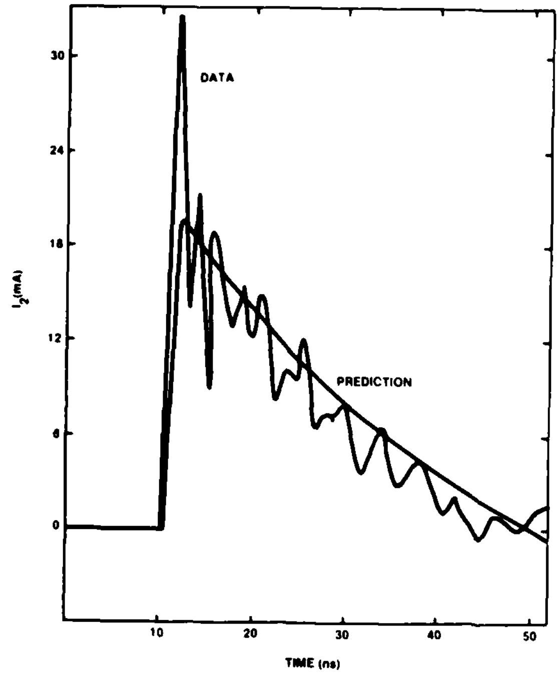

Figure 8. Experiment 3: predictions and data for vertical loop current I_2 at Scale Modeling Facility. Data taken with signal ground connected to bonded grid at B and grid connected to earth ground at A and B.

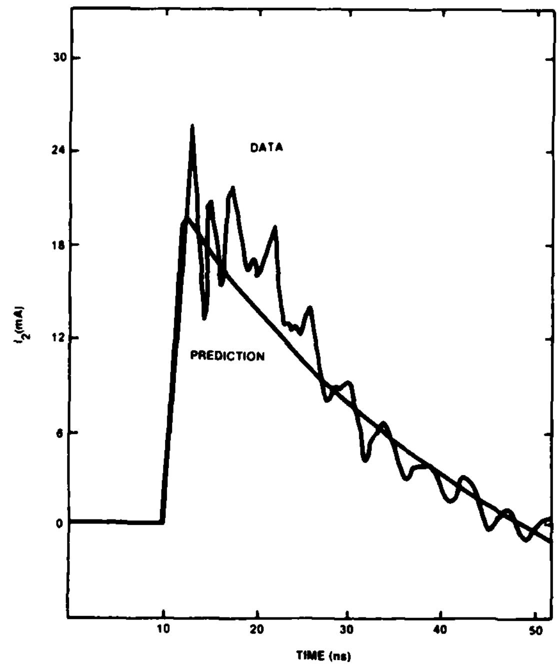

Figure 9. Experiment 4: predictions and data for vertical loop current I_2 with bonded grid connected to earth ground at A.

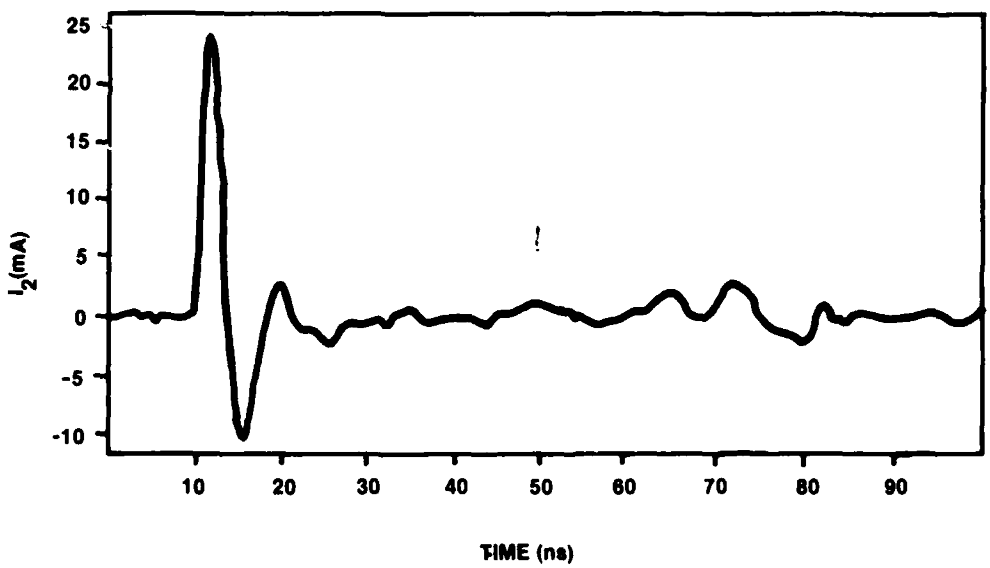

Figure 10. Current I_2 from experiment 3 (without metal ground plane).

4. SUMMARY OF RESULTS

The major conclusions resulting from this study are summarized as follows:

(a) The type of earth ground system does not appear to be important.

(b) Location of connections (and whether or not connections are made) of the signal ground plane to the earth ground system does not appear to be important.

(c) The earth ground system can increase currents on a coarse grid signal ground structure when they are connected together.

(d) The earth ground system does not increase the response of test loops on a continuous metal ground plane when the plane and earth ground system are connected together.

(e) Currents on the order of hundreds of amperes are induced on the earth ground system by HEMP (Example: 84 mA × [(50,000 V/m)/(59 V/m)] × 10 = 712 A).

(f) Adding ground rods made little difference in the response.

A second useful result is the consistently close agreement between the relatively simple theoretical model and the test results. This suggests that the model should prove useful for future studies when extensive testing is not possible.

The basic results of this study show that the choice of the earth ground system and how it connects to the signal ground plane do not affect the free-field EMP response of intrafacility cables. The choice of grounding system can be based on other considerations.

One item, not yet taken into account, needs to be mentioned. Most facilities have long lines which can inject a large current into the facility. The effect of the different ground systems under these conditions has not yet been addressed, and it is a worthwhile subject for future research. However, it is not expected that the choice of the earth ground system will be significant here either, although the way in which the EMP cable currents are "bled off" by spark gaps, etc., is expected to be significant.

APPENDIX A.--CALCULATION OF WIRE RESONANCE

The wire resonance is estimated below.

The total electrical length of the wire is

$$\left[1.5 + 5/12 + 5/12 + 2\left(6/12 + 6/12\right)\right] \text{ft} = 4.33 \text{ ft} \quad ,$$

$$= 1.32 \text{ m} \quad .$$

Computing the half-wave resonant frequency,

$$\ell = \lambda/2 \quad ,$$

$$\lambda = 2\ell = 2(1.32) = 2.64 \text{ m} \quad ,$$

$$f = \frac{3 \times 10^8 \text{ m/s}}{2.64} = 1.14 \times 10^8 \quad ,$$

$$f = 0.114 \times 10^9 \text{ Hz} \quad ,$$

and

$$f = 0.114 \text{ GHz} \quad .$$

from the data f = 0.125 GHz.

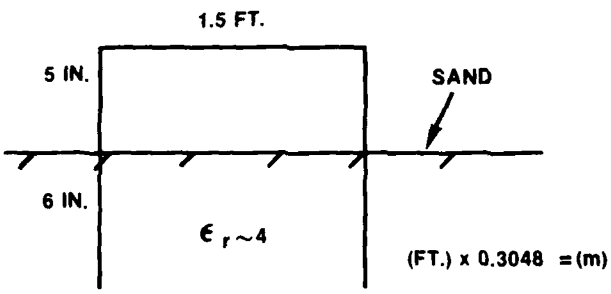

Figure A-1. Calculation of wire resonance (resonance is estimated).

DISTRIBUTION

ADMINISTRATOR
DEFENSE TECHNICAL INFORMATION CENTER
CAMERON STATION, BUILDING 5
ATTN DTIC-DDA (12 COPIES)
ALEXANDRIA, VA 22314

ASSISTANT TO THE SECRETARY OF DEFENSE
ATOMIC ENERGY
ATTN EXECUTIVE ASSISTANT
WASHINGTON, DC 20301

DEPUTY DIRECTOR FOR THEATRE/TACTICAL C
SYSTEMS
JOINT STAFF
WASHINGTON, DC 20301

COMMANDER
US ARMY RSCH & STD GP (EUR)
ATTN CHIEF, PHYSICS & MATH BRANCH
FPO NEW YORK 09150

COMMANDER
US ARMY MISSILE & MUNITIONS CENTER
& SCHOOL
ATTN ATSK-CTD-F
RESTONE ARSENAL, AL 35809

DIRECTOR
US ARMY MATERIEL SYSTEMS ANALYSIS
ACTIVITY
ATTN DRXSY-MP
ABERDEEN PROVING GROUND, MD 21005

US ARMY BALLISTIC RESEARCH LABORATORY
ATTN DRDAR-TSB-S (STINFO)
ABERDEEN PROVING GROUND, MD 21005

US ARMY ELECTRONICS TECHNOLOGY &
DEVICES LABORATORY
ATTN DELET-DD
FT MONMOUTH, NJ 07703

HQ, USAF/SAMI
WASHINGTON, DC 20330

TELEDYNE BROWN ENGINEERING
CUMMINGS RESEARCH PARK
ATTN DR. MELVIN L. PRICE, MS-44
HUNTSVILLE, AL 35807

ENGINEERING SOCIETIES LIBRARY
ATTN ACQUISITIONS DEPARTMENT
345 EAST 47TH STREET
NEW YORK, NY 10017

DIRECTOR
DEFENSE COMMUNICATIONS AGENCY
ATTN CODE B430
WASHINGTON, DC 20305

DIRECTOR
DEFENSE COMMUNICATIONS ENGINEERING CENTER
ATTN CODE R400
ATTN CODE R123, TECH LIB
ATTN CODE R800, COL. F. MAYBAUM
(20 COPIES)
1860 WIEHLE AVENUE
RESTON, VA 22090

DIRECTOR
DEFENSE INTELLIGENCE AGENCY
ATTN DB-4C2, D. SPOHN
WASHINGTON, DC 20301

DIRECTOR
DEFENSE NUCLEAR AGENCY
ATTN NATA
ATTN RAEE
ATTN TITL
WASHINGTON, DC 20305

CHAIRMAN
JOINT CHIEFS OF STAFF
ATTN J-3, ELECTRONIC WARFARE DIV
WASHINGTON, DC 20301

NATIONAL COMMUNICATIONS SYSTEM
OFFICE OF THE MANAGER
DEPARTMENT OF DEFENSE
ATTN NCS-TS
WASHINGTON, DC 20305

UNDER SECY OF DEF FOR RSCH & ENGRG
DEPARTMENT OF DEFENSE
ATTN STRATEGIC & SPACE SYS (OS) RM 3E129
ATTN STRAT & THEATER NUC FORCES
WASHINGTON, DC 20301

DEP CH OF STAFF FOR RSCH DEV & ACQ
DEPARTMENT OF THE ARMY
ATTN DAMA-N-CSS
WASHINGTON, DC 20310

ASSISTANT CHIEF OF STAFF FOR
AUTOMATION & COMMUNICATIONS
ATTN DAMO-C4T
DEPARTMENT OF THE ARMY
WASHINGTON, DC 20360

COMMANDER
US ARMY COMM-ELEC INSTAL AGENCY
ATTN CCC-CED-XES
FT HUACHUCA, AZ 85613

COMMANDER
US ARMY COMMUNICATIONS COMMAND
ATTN CC-OPS-WR
ATTN CC-OC-SAP

US ARMY COMMUNICATIONS COMMAND (Cont'd)
ATTN CC-ENGR
ATTN ATSI-CD-MD
ATTN CC-OPS-OT, O. P. CONNELL
FT HUACHUCA, AZ 85613

CHIEF
US ARMY COMMUNICATIONS SYS AGENCY
DEPARTMENT OF THE ARMY
ATTN CCM-AD-SV
ATTN CCM-RD-T
FT MONMOUTH, NJ 07703

US ARMY COMMUNICATIONS SYSTEMS AGENCY
ATTN TECHNICAL DIRECTOR
FELICIANO GIORDANO (2 COPIES)
FT MONMOUTH, NJ 07703

COMMMANDER
US ARMY SATELLITE COMMUNICATIONS AGENCY
ATTN DRCPM-SC
FT MONMOUTH, NJ 07703

DIVISION ENGINEER
US ARMY ENGINEER DIV HUNTSVILLE
ATTN HNDED-SR
PO BOX 1600, WEST STATION
HUNTSVILLE, AL 35807

DIRECTOR, NAVAL TELECOMMUNICATIONS DIVISION
OFFICE OF THE CHIEF OF NAVAL OPERATIONS
ATTN OP943
DEPARTMENT OF THE NAVY
WASHINGTON, DC 20350

COMMANDER
NAVAL ELECTRONIC SYSTEMS COMMAND
ATTN PME 110-241D/D. O'BRYHIM
WASHINGTON, DC 20360

COMMANDER
NAVAL TELECOMMUNICATIONS COMMAND
ATTN CODE 621A
4401 MASSACHUSETTS AVE, NW
WASHINGTON, DC 20390

COMMANDER
NAVAL OCEAN SYSTEMS CENTER
ATTN CODE 7309, R. GREENWELL
ATTN CODE 8123, S. LICHTMAN
SAN DIEGO, CA 92152

COMMANDING OFFICER
NAVAL ORDNANCE STATION
ATTN STANDARDIZATION DIVISION
INDIANHEAD, MD 20640

COMMANDING OFFICER
NAVAL RESEARCH LABORATORY
ATTN CODE 4720, J. DAVIS
WASHINGTON, DC 20375

COMMANDER
NAVAL SURFACE WEAPONS CENTER
ATTN CODE F32, E. RATHBURN
ATTN CODE F30
WHITE OAK LABORATORY
SILVER SPRING, MD 20910

COMMANDER
NAVAL SURFACE WEAPONS CENTER
ATTN CODE F-56
DAHLGREN, VA 22448

NAVFAC ENG COM PAC DIV
ATTN RON CHING
PEARL HARBOR
OAHU, HI 96860

COMMANDER-IN-CHIEF PACIFIC
ATTN C35 2000
CAMP H. M. SMITH, HAWAII 96861

AIR FORCE WEAPONS LABORATORY/DYC
ATTN NTYCS
KIRTLAND AFB, NM 87117

HEADQUARTERS
ELECTRONIC SYSTEMS DIVISION/YS
ATTN YSEA
HANSCOM AFB, MA 01730

AIR FORCE COMMUNICATIONS COMMAND
ATTN EPPD
SCOTT AFB, IL 62225

SYSTEM INTEGRATION OFFICE
ATTN SYE
PETERSON AFB, CO 80912

LAWRENCE LIVERMORE NATIONAL LAB
ATTN TECHNICAL INFO DEPT LIBRARY
ATTN L-156, H. CABAYAN, L. MARTIN
PO BOX 808
LIVERMORE, CA 94550

CENTRAL INTELLIGENCE AGENCY
ATTN OWSR/NED
ATTN OWSR/STD/MTB, A. PADGETT
WASHINGTON, DC 20505

DIRECTOR
FEDERAL EMERGENCY MANAGEMENT AGENCY
OFFICE OF RESEARCH/NPP
ATTN STATE & LOCAL PROG SUPPORT
500 C STREET, SW
WASHINGTON, DC 20472

DISTRIBUTION (Cont'd)

FEDERAL PREPAREDNESS AGENCY
GENERAL SERVICES ADMINISTRATION
ATTN ESTE-M MURTHA
18TH & F STREETS, NW
WASHINGTON, DC 20405

AMERICAN TELEPHONE & TELEGRAPH CO
ATTN SEC OFC FOR W. EDWARDS
1120 20TH STREET, NW
WASHINGTON, DC 20036

BDM CORP
ATTN CORPORATE LIBRARY
7915 JONES BRANCH DRIVE
MCLEAN, VA 22102

BOEING CO
ATTN V. JONES
PO BOX 3707
SEATTLE, WASHINGTON 98124

ELECTRO MAGNETIC APPLICATIONS, INC
ATTN R. PERALA
PO BOX 26263
1978 SOUTH GARRISON ST
DENVER, CO 80226

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
ATTN RES & SEC COORD FOR H. DENNY
ATLANTA, GA 30332

IIT RESEARCH INSTITUTE
10 W 35TH STREET
ATTN J. BRIDGES
ATTN I. MINDEL
CHICAGO, IL 60616

INTERNATIONAL TEL & TELEGRAPH CORP
ATTN A. RICHARDSON
ATTN TECHNICAL LIBRARY
500 WASHINGTON AVENUE
NUTLEY, NJ 07110

MISSION RESEARCH CORP
EM SYSTEM APPLICATIONS DIVISION
ATTN A. CHODOROW
1400 SAN MATEO BLVD, SE, SUITE A
ALBUQUERQUE, NM 87108

R&D ASSOCIATES
ATTN DIRECTOR, DR. JAMES THOMPSON
1401 WILSON BLVD
SUITE 500
ARLINGTON, VA 22209

ROCKWELL INTERNATIONAL CORP
ATTN D/243-068, 031-CA31
ATTN G. MORGAN
PO BOX 3105
ANAHEIM, CA 92803

SRI INTERNATIONAL
ATTN A. WHITSON
ATTN E. VANCE
333 RAVENSWOOD AVENUE
MENLO PARK, CA 94025

TRW DEFENSE & SPACE SYSTEMS GROUP
ATTN J. PENAR
ATTN W. GARGARO
ATTN R. LOWELL
ONE SPACE PARK
REDONDO BEACH, CA 90278

US ARMY ELECTRONICS RESEARCH
& DEVELOPMENT COMMAND
ATTN COMMANDER, DRDEL-CG
ATTN TECHNICAL DIRECTOR, DRDEL-CT
ATTN PUBLIC AFFAIRS OFFICE, DRDEL-IN

COMMANDER
HARRY DIAMOND LABORATORIES
ATTN CO/TD/TSO/DIVISION DIRECTORS
ATTN RECORD COPY, 81200
ATTN HDL LIBRARY, 81100 (3 COPIES)
ATTN HDL LIBRARY (WOODBRIDGE)
ATTN TECHNICAL REPORTS BRANCH, 81300
ATTN LEGAL OFFICE, 97000
ATTN CHAIRMAN, EDITORIAL COMMITTEE
ATTN R. E. MORRISON, 13500
ATTN CHIEF, 21000
ATTN CHIEF, 21100
ATTN CHIEF, 21200
ATTN CHIEF, 21300 (20 COPIES)
ATTN CHIEF, 21400
ATTN CHIEF, 21500
ATTN CHIEF, 22000
ATTN CHIEF, 22100
ATTN CHIEF, 22300
ATTN CHIEF, 22800
ATTN CHIEF, 22900
ATTN CHIEF, 20240
ATTN G. BOSWELL, 21500
ATTN S. BUKALSKI, 22100
ATTN J. LOFTUS, 21400 (10 COPIES)
ATTN A. CUNEO, 21100 (20 COPIES)